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THERMAL PERFORMANCE ANALYSIS ON STAGGERED FINNED ABSORBER SOLAR AIR HEATER

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ABSTRACT

Analysis of thermal performance analysis on the staggered fin solar air heater has been carried out theoretically in this paper. Thermal efficiency indicates the part by which incident solar energy is converted to useful work output on the other hand thermohydrauic efficiency inform about the fraction of incident energy transformed to desired need. A analytical study has been carried out to investigate the number of effect of system and various operational parameters i.e. space between fins, vertical length of fin, mass flow rate of air and insolation 960 W/m2 on the thermal and thermohydraulic efficiency. The analytical approach provides adequate information of the performance of offset finned solar air heater and it helps in designing such types of solar air heater. The analytical methodology gives sufficient premonition of the execution of offset finned solar air heater and it very well may be useful in designing such kinds of solar air heater.

KEYWORDS: *Solar Air Heater, Fin Spacing, Thermal Efficiency & Effective Efficiency*

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Original Article

1. INTRODUCTION

With new progressions in scientific examinations, solar based energy could be more sparing in future with ease and high productivity. It is most essential amidst sustainable power source assets because of its quantifiable simplicity. The easy and the most effective approach to use sunlight based vitality are to change over it into warm vitality for warming applications. The flat plate solar air heater has an captivate radiative warmth exchanger, convert sun powered radiant energy into warmth, which is go on through convection from the absorber plate to the air. Solar air heater can be utilized satisfactorily for various applications, i.e. crops drying and restorative plants to quell the loss of therapeutic impact from direct radiation, moisture removal of food, warming of room and warm stockpiling. By prudence of lower thermo physical properties of air, extended surfaces, i.e. packed beds, rough surface absorber, and baffles are utilized to enhance the heat exchange rate without expanding the size of absorber plate (Duffie and Beckman, 1980; Krieder and Krieth, 1978). An experimental examination was finished by Youcef, A. S., (2005) to research the thermal execution of an offset rectangular plate fin fixed below the surface of absorber plate in staggered way and directed parallel to the flow of air. Results demonstrate that by high thermal exchange surface zone per unit volume are acquired high heat transfer with low pressure drop loss. Ming, Y., et al (2014) structured and enhanced a solar air heater with staggered strip fin by analytical modelling. The work was helpful for making energy efficient and financially effective solar air heaters. Another researcher, Youcef, A. S., Desmons, J. Y (2006) built up a numerical model to evaluate the thermal performance of the single pass solar air heater with staggered fin absorber plate.

Result depicts that heat transfer surface area per unit volume increases, pressure loss go down and Hachemi, A (1999) analyzed the work performance of staggered rectangular plate fins and found the other technique to enhance the heat transfer more compare to fully developed turbulent flow. From the above result the high thermal work performances were obtained with low flow friction and in a result low electrical power consumption by the fan in comparison to the flat plate collector. Junqi, D., et al (2007) studied eighteen different types of offset strip fins to get the air-side heat transfer and pressure drop characteristics. And flat tube heat energy exchangers were performed experimentally. The heat transfer coefficients and pressure drop data with different fin spacing, height of fin, and length of fin were done in terms of the frontal air velocity of fluid. The theoretical analysis of the thermal and thermohydraulic performance of wavy finned absorber plate solar heater by Priyam, A. and Chand, P. (2016). Effect of mass flow rate and fin spacing on the performance of solar air heater were found by them. An experimental study based on energy and exergy analysis has done by Alta, D., et al. (2010) for determining the performance of four different types of flat-plate solar air heaters. Results of them informed that the energy and exergy efficiencies of above said air heater with attached fins and doubly glass cover are higher. An experimental evaluation of evaluated the energy and exergy efficiency by Esen, H (2008) on four types of flat-plate solar air heaters with and without obstacles on the absorber plate. From the analysis, found that all of three solar air heaters with obstacle on the absorber plate show better performance in comparison with the one without obstacle.

It is obvious that air speed is controlled by geometric structure of solar collector and forced convection is also affected. A conventional procedure of controlling of air stream and the hindrance of forced convection integrate by changing the channel pipe of stream framework with offset finned connected below the absorber plate.

In this paper, an analytical investigation on elemental volume of offset finned attached below the collector plate of solar air heater will be analysied. Consequence of geometric shape and variable operating parameters such as spacing of fin, height of fin and mass flow rate of air on thermal and thermohydraulic performance will also be informed and results will also be compared with conventional flat plate solar air heater.

2. THEORETICAL ANALYSIS

Here a line diagram of solar air heater is displayed, made by using Auto Cad software. The width, height and length of the channel is W, D and L respectively. The height of the fine is 'h_f' length is 'l_f' thickness 't_f' and offset spacing 's_f' respectively.

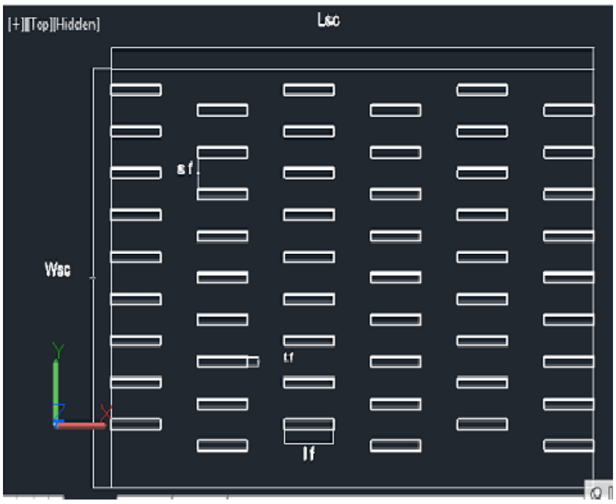

Figure 1: Solar Air Heater Absorber Plate with Parameters of Offset.

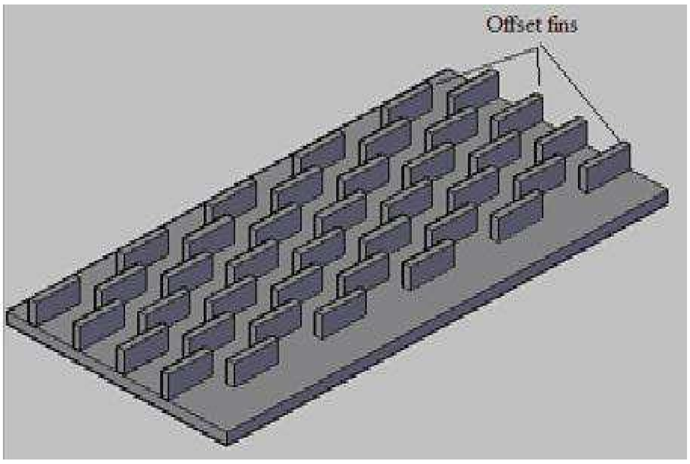

Figure 2: Schematic Diagram of Bottom View Absorber Plate attached with Offset Fin.

The following assumptions have been considered before developing the general heat balance equation.

- Flow is considered as steady state.
- Heat absorbed by glass covered is zero.
- Unidimensional heat transfer across glass cover and back side insulation
- The covers are opaque to infrared radiation
- Inside heat generation is zero
- Shape factor is chosen high

2.1. General Heat Balance Equations

An elemental strip is considered of width ‘W’ thickness ‘dx’ at a distance of x from the flow inlet side. Now, energy balance equation is written in the following way for the bottom plate and the absorber plate.

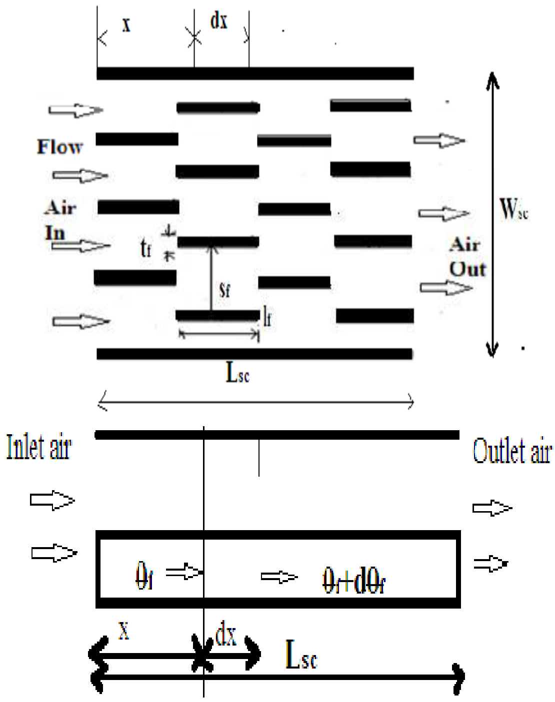

Figure 3: Top View of the Absorber Plate with Offset Finned.

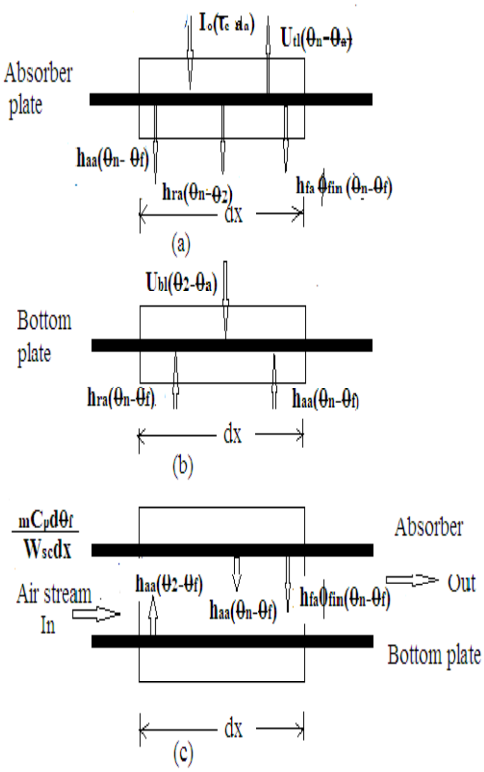

Figure 4: Energy Balance Equation Unidimensional Steady State Flow (a) Solar Heater Absorber Plate (b) Glass Cover Plate and (c) Air Stream in the Offset Finned Solar Air Heater.

From the above figure (a)

Io(Tcαb) = Utl(θn-θa)+haa(θn-θf)+hfaφfin(θn-θf)+hra(θn-θ_2) (1)

From the above figure (b)

haa(θn-θf)+Ub(θ2-θa)=hra(θn –θ_2) (2)

And from the figure (c)

haa$(\theta_2 - \theta_f)$ + haa$(\theta_n$-θf) + hfaφfin(θn-θf) =$\frac{C_p \theta_f \dot{m}}{W_{sc} dx}$ (3)

The non-dimensional quantityφ_{fin} may be defined as:

$$\varphi_{fin} = \left[\frac{A_t}{A_{sc}}\right]\eta_{fin}+1$$

Total fin surface area A_t and efficiency finη_{fin} is evaluated as:

$$A_t = \frac{4(l_f h_f + t_f h_f) W_{Sc} L_{sc}}{2 l_f (S_f + t_f)}$$

And $\eta_{fin} = \frac{\tanh(MDh)}{MD_h}$

$$M = \sqrt{\frac{2h_f}{K_{fin} t_f}}$$

2.2. Effective Heat Transfer Coefficient

According to Duffie and Beckman, effective heat transfer coefficient is

$$\frac{1}{\varepsilon} = \frac{1}{\varepsilon_a} + \frac{1}{\varepsilon_b} - 1$$

$$h_{ra} = \sigma_{sb}\varepsilon(\theta_n + \theta_2)(\theta_n^2 + \theta_2^2)$$

where the temperature θ_n and θ_2 are in Kelvin. The average heat transfer coefficient is given as:

$$h_{aa} = \frac{N_{un}K_{air}}{d_e} = h_{ba} = h_{fa}$$

Non-dimensional Reynolds number may be evaluated as

$$R_{en} = V_{aa}\left(\frac{d_e}{v_e}\right)$$

The average velocity may be written as

$$V_{aa} = \left(\frac{\dot{m}}{\rho a A c s}\right)$$

2.3. Equation for Temperature Distribution

Outlet air temp of solar air collector may be determined from an energy balance eqn

$$\frac{\theta_{fo} - \theta_a}{\theta_{fi} - \theta_a - \frac{S}{u_{OL}}} = \exp\left[\frac{A_{cs}U_{OL}F'C}{\dot{m}c_p}\right]$$

The average air stream temperature may be written as

$$\theta_f = \theta_{fi} + \left[\frac{\frac{Q_{ug}}{A_{sc}}}{F_{HR}U_{OL}}\right]\left[1 - \frac{F_{HR}}{F_c'}\right]$$

2.4. Thermal Efficiency of Solar Air Heater

The thermal efficiency may be calculated as:

$$\eta_{th} = \frac{Q_{ug}}{I_o A_{sc}}$$

$$Q_{ug} = AscF_{HR}[S\text{-}U_{OL}[\theta_{fi} - \theta_a]]$$

$$\eta_{th} = \frac{\dot{m}C_p(\theta_{fo} - \theta_{fi})}{I_o A_{sc}}$$

2.5. Thermohydraulic Performance

Thermohydraulic performance of offset finned solar air heater can be reached up to optimum value by taking the conversion factor which is reason for actual energy gain from conversion of primary energy to mechanical energy. For evaluating the thermohydraulic performance of the collector, the following formula for effective efficiency is used in this analysis.

For blowing the air through a duct mechanical power P_m required is given by

$$Pm = \frac{\dot{m}\Delta Pd}{\rho_a}$$

When air flow through a duct pressure drop takes place and that can be found from the given expression

$$\Delta P_d = \frac{f_p L_{sc} \rho_a V^2}{2 d_e}$$

3. RESULTS AND DISCUSSIONS

A stipulated code was developed by taking consideration of the following system, properties and their operating conditions as mentioned for an analytical investigation on thermal and thermohydraulic performance of staggered finned absorber solar air heater.

By using MATLAB, a specific code had been developed by the following system, operating variable and system properties taking as consideration, enlisted below.

Table 1: Operating Variable and System Properties

Operating Parameter	Numerical Value
Length of the Collector,	1.50 m
Width of the Collector,	1 m
Channel Duct Height,	2 cm to 6 cm
Offset fin Height,	1.8 cm to 5.8 cm
Offset fin Spacing,	1 cm to 5 cm
Offset fin Length,	2 cm
Offset fin Thickness,	3 mm
Mass Flow Rate in kg/s,	0.01389 kg/s to 0.0833 kg/s
Mass Flow Rate in kg/h,	50 kg/h to 300 kg/h
Product of Transmissivity and Absorptivity,	0.85
Solar Insolation,	950 W/
Insulation Thickness,	4 cm
Insulation Thermal Conductivity,	0.033 W/m-K
Ambient Temperature,	298 K
Specific Heat of Air,	1.005 kJ/kg-K
Thermal Conductivity of Air,	0.02826 W/m-K
Kinematic Viscosity of Air,	18.97×
Wood Emissivity,	o.93
Glass Emissivity,	0.88
Back Plate Emissivity,	0.9

It can be concluded from the below figure that how efficiency of solar air heater changes with variable parameter like air mass flow rate, fin spacing, offset of fin and other variable parameter.

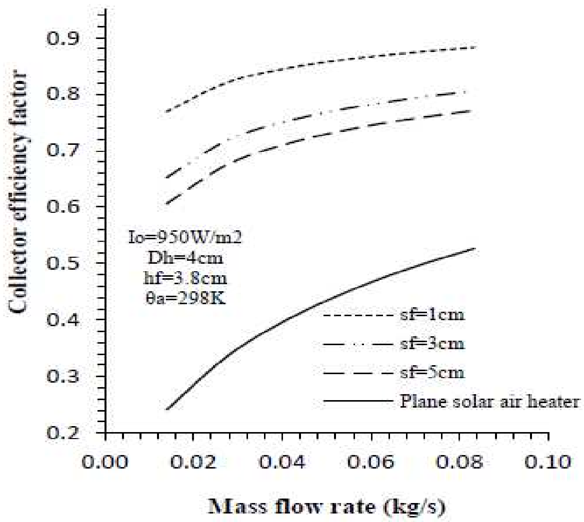

Figure 5: F_c' vs $\dot{m}$ for Different Fin Spacing.

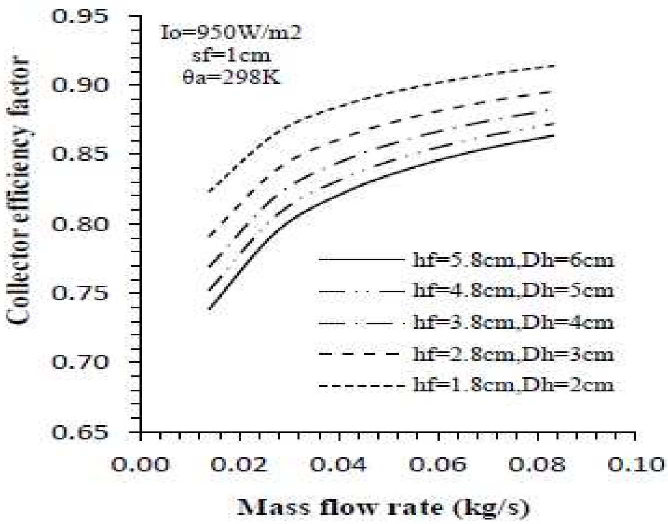

Figure 6: F_c'vs$\dot{m}$ for Different Fin Height.

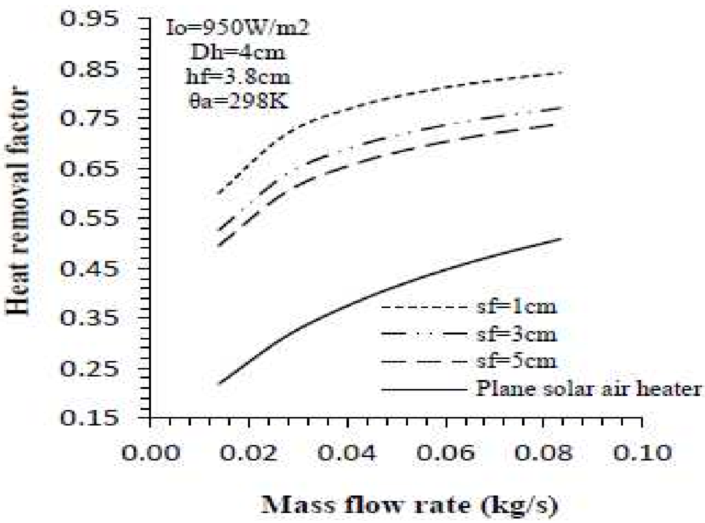

Figure 7: F_{HR}vs$\dot{m}$ for Different Fin Spacing.

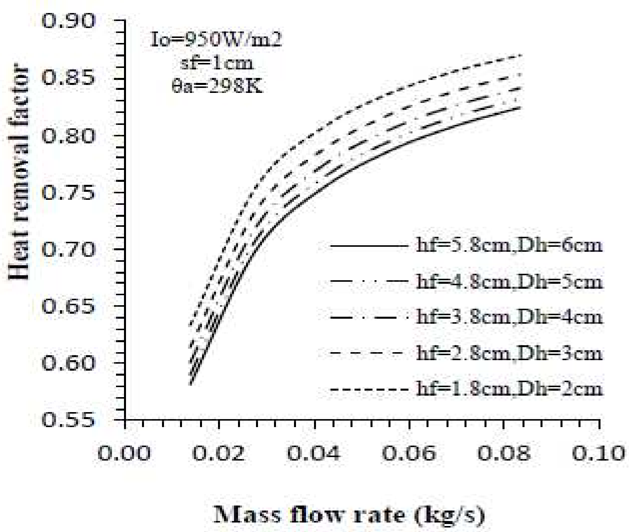

Figure 8: F_{HR}vs$\dot{m}$ for Different Fin Height.

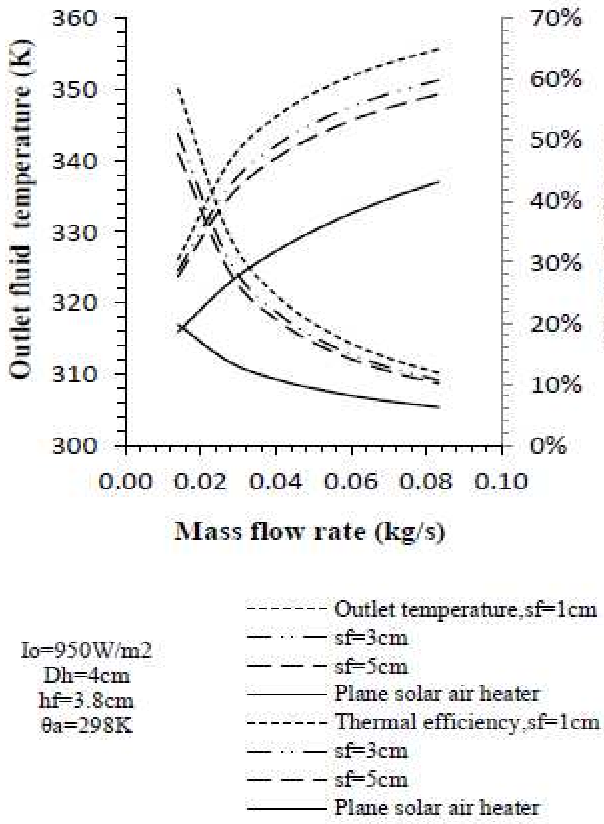

Figure 9: Fluid Outlet Temp. vs$\dot{m}$ for Different Fin Spacing.

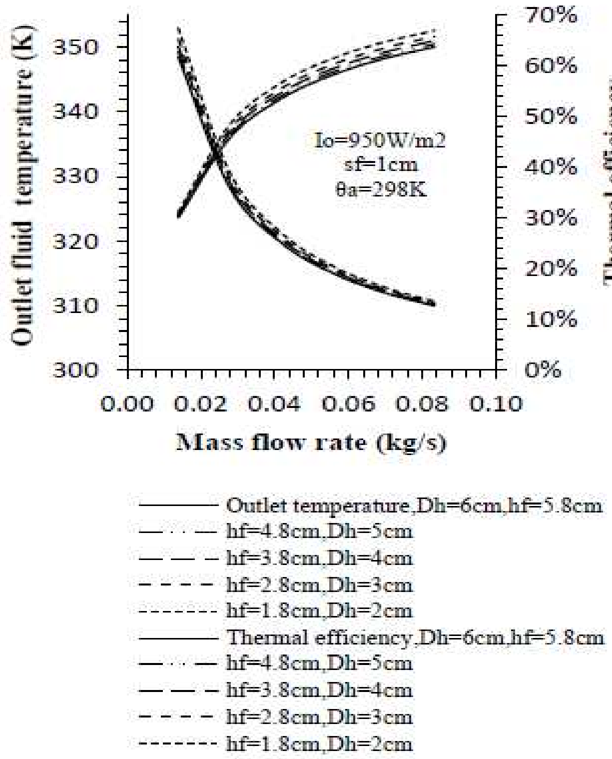

Figure 10: Fluid Outlet Temp, Thermal Eff. Vs $\dot{m}$ for Different Fin Spacing.

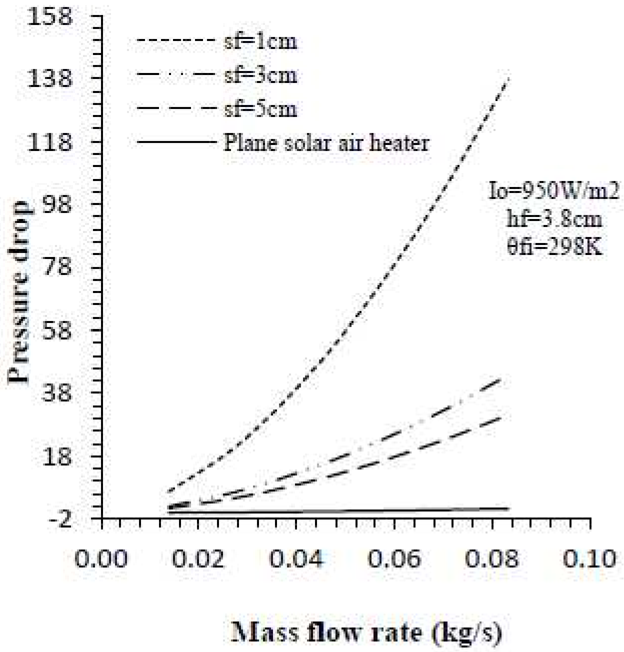

Figure 11: ΔP_dvs $\dot{m}$ for Different Fin Spacing.

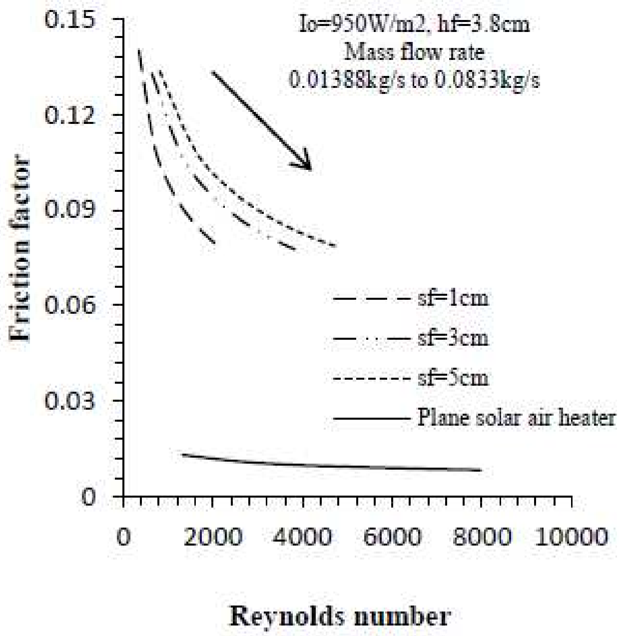

Figure 12: f_p Vs Re for Different Fin Spacing.

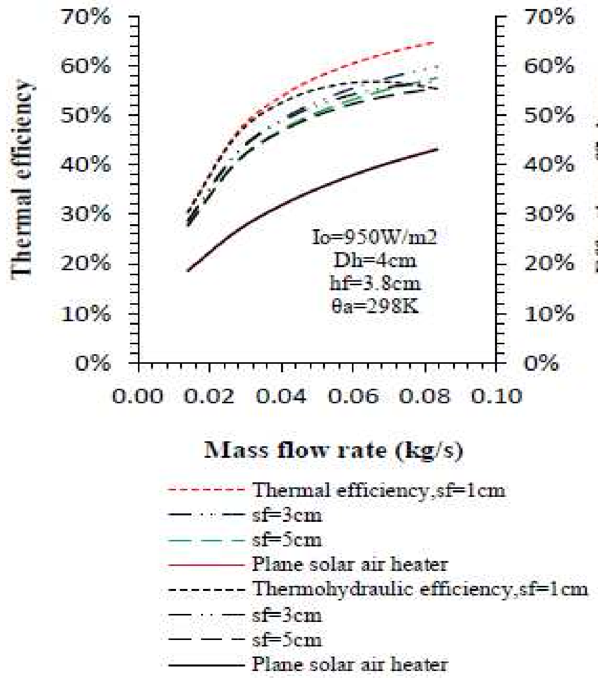

Figure 13: Thermal Efficiency Vs. $\dot{m}$ for Diff Fin Spacing.

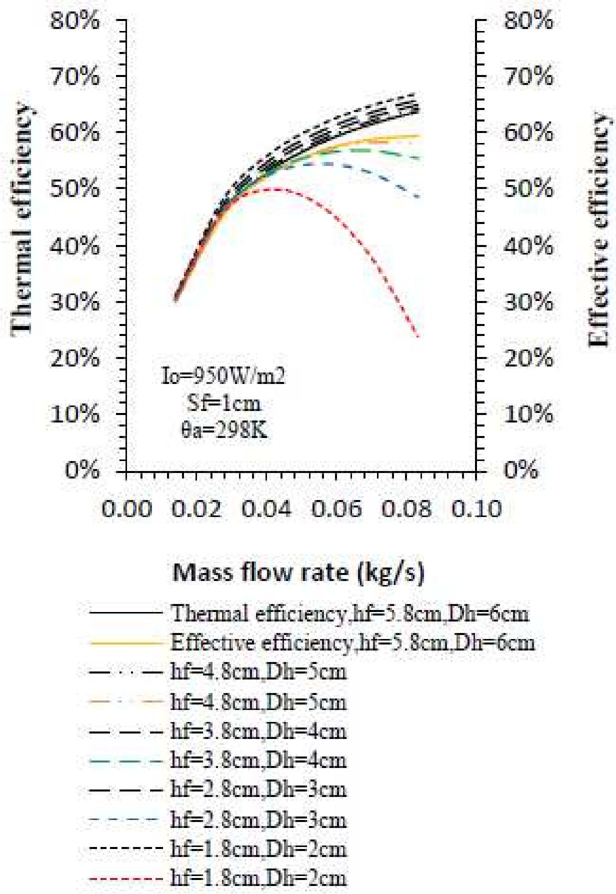

Figure 14: Thermal and Effective Efficiency Vs. $\dot{m}$ for Diff. Fin Spacing.

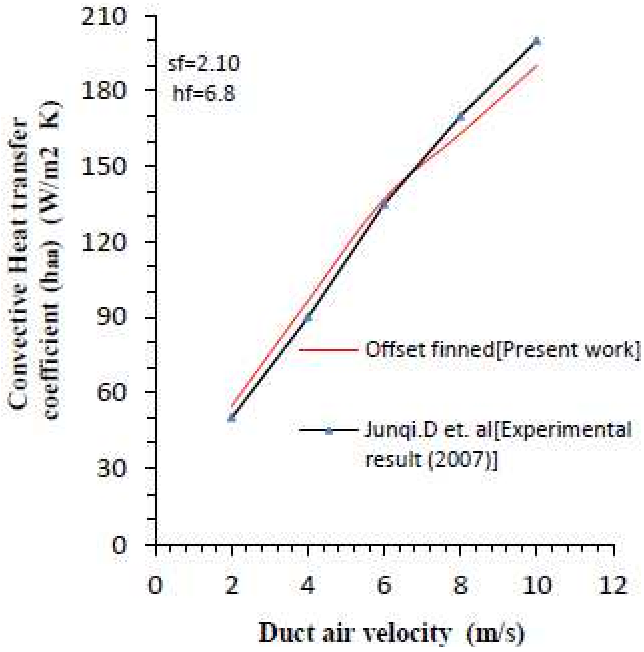

Figure 15: Convective Heat Transfer Coefficient Vs. Duct Air Velocity.

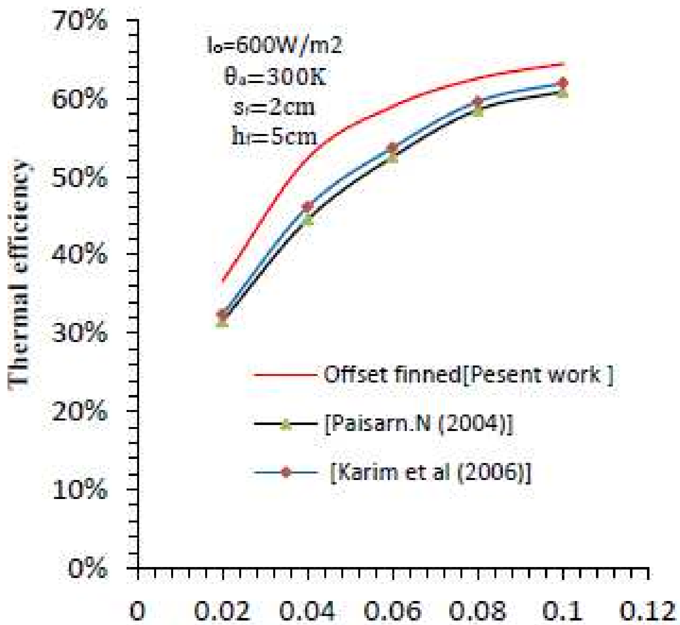

Figure 16: Thermal Efficiency Vs. Rate of Mass Flow.

4. CONCLUSIONS

Here, in the paper analytical work has been done considering insulation 950W/m^2 and taking operating parameter like mass flow, fin spacing, and height of fin. Analytically it was found that inserting staggered fins below the absorber plate is the best way to improve heat transfer enhancement rate in solar air heater. It happens because of turbulence created by staggered fins. Due to turbulence, convective heat transfer increases, consequently heat transfer rate increases. It is reached to the following conclusion considering above result & discussion.

- Analytical analysis provide sufficient information about prediction of performance of solar heater with and without staggered fins.
- Based on parametric study on the staggered finned absorber plate the numerical value of outlet air temperature, factor of heat removal, friction factor and pressure drop has been determined by approach of analytical method.
- Calculated numerical value of solar air heater with fin and without fin were compared.
- Eventually it was found that best thermal and thermohydraulic performance is achieved by putting small fin spacing, small fin height and low mass flow rate.

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